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MODELLING AND ANALYSIS OF THERMO ELECTRIC COOLER MODULE USING ANSYS

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ABSTRACT

In the recent years, dealing with many troubles together with energy crisis and environment degradation due to the increasing CO_2 emission levels has grown to be the basically challenge to both developed and growing countries. The research work is proposed to carry on modelling and analysis of thermoelectric cooler (TEC) module contains a copper and Aluminium fins of long and short type. The innovative idea is to apply the solar energy input rather than D.C. electrical input power on thermoelectric module is going to be one of the most cost effective, clean and environment friendly system. Hence the purpose of this work is to identify the temperature and heat flux distribution on TEC modules of copper and Aluminium type of fins for a given solar electric power input supply conditions. Coefficient of performance of a TEC module is very low and the thermal designers have to think on to increase fin area and fan speed to improve its cooling capacity. However, the increase of fin area is restricted by the space. The variation in temperature and heat flux distribution effect on TEC module varies with increasing input current for Copper and Aluminium fins on cold reservoir.

***KEYWORDS:** Thermoelectric Cooler, TEC-1, TEC-2, Thermoelectric Cooling/Heating, Heat Sink & Peltier Effect*

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Original Article

INTRODUCTION

Thermoelectric is defined as the generation of electricity from a given temperature difference or vice versa. Solid state devices capable of producing power, these devices are environment friendly that come with low maintenance and reliability. The concept of thermoelectricity can be classified into two parts. i.e. Thermoelectric Coolers (TEC) module and Thermoelectric Generators (TEG) module. When an electrical current passes through the unit module, a finite temperature difference is observed between two junctions. Temperature at one junction becomes higher than the ambient and at other junction lower than the ambient. This “power input to temperature difference” is known as the Peltier effect. Therefore, the cold junction can absorb thermal energy from reservoir and the hot junction can reject heat to surrounding environment. Thermoelectric cooling, also called “Peltier cooling” is a solid-state method of heat transfer through dissimilar semiconductor materials. Coefficient of performance for thermoelectric cooling system is discussed here with single stage thermoelectric module. TECs inherently have many advantages over the alternate types of refrigeration. Figure 1 shows the entire fabrication of thermoelectric cooling system. The general measure of efficiency of a TEC is based on the amount of heat that it removes compared to the amount of work that it requires. Matthieu Cosnier et al., [1] presented an experimental and numerical study of a thermoelectric air-cooling and air-heating system and were reported a cooling power of 50 W per module with a coefficient of performance (COP) in between 1.5 and 2. The electrical

intensity of 4 amps power input is supplied and maintained the 5°C temperature difference between the hot and cold sides. Suwit Jugsujinda et al.,[2] conducted an experiment to analyse COP of thermoelectric refrigerator performance. The refrigeration system of thermoelectric refrigerator(TER) with a size of 25 × 25 × 35 cm^3 was fabricated by using a thermoelectric cooler (TEC) with a size of 4 × 4 cm^2) and applied electrical input power of 40 W. The temperature of TER has decreased from 30 ºC to 20 ºC in one hour time period and slowly the cooling temperature dropped gradually. The maximum COP of TEC and TER were 3.0 and 0.65. Wei He et al., [3] done work on numerical study of Theoretical and experimental investigation of a thermoelectric cooling and heating system driven by solar. In summer, the thermoelectric device works as a Peltier cooler when electrical power input supplied by thermal photovoltaic modules. The air cooling temperature of 17 ^{0}C was achieved with COP of 0.45 with the thermoelectric device. Riff and Guoquan et al., [4] showed an experimental study of comparative investigation of thermoelectric air conditioners versus vapour compression and absorption air conditioners. Three types of domestic air conditioners were compared and fabricated a compact air conditioner. Nagyet et al., [6] focused on modelling and optimization of the thermoelectric heat sink with proper design of the thermoelectric cooling systems. Collectively, TE material researchers have spent tens of millions of dollars to advance the performance level of TE materials with some effective heat sink designs. The combination of detailed thermal modelling and high-speed personal computers makes it no less effort to fully optimize a heat sink design. Riffat and Qiu et al., [7] compared the performances of thermoelectric and conventional vapour compression air-conditioners. Results showed that the actual COPs of vapour compression and thermoelectric air-conditioners are in the range of 2.6-3.0 and 0.38-0.45, respectively. However, thermoelectric air conditioners have several advantageous features compared to their vapour-compression counterparts. Astrain, et. al., [8] steered the COP in the thermoelectric refrigeration by optimizing heat dissipation. Thermoelectric refrigeration based on the principle of a thermos syphon with phase change is also presented. In the experimental optimization phase, a prototype of thermo syphon with a thermal resistance of 0.110 K/W has been developed, dissipating the heat of a Peltier pellet with the size of 40*40*3.9 cm^3, experimentally proved that the use of thermos syphon with phase change increases the coefficient of performance up to 32%. Shen, Xiao et al., [9] investigated a novel thermoelectric radiant air-conditioning system (TE-RAC). The system on thermoelectric air-conditioner using Peltier Module employs thermoelectric modules as radiant panels for indoor cooling, as well as for space heating by easily reversing the input current. The commercial thermoelectric module they have obtained a maximum cooling COP of 1.77 with an electric input current of 1.2 amp. and obtained the recorded cold side temperature 20°C. Virjoghe, Diana et al., [10] conducted a numerical investigation of thermoelectric System. The thermoelectric systems have attracted renewed interest as concerns with the efficient use of energy resources, and the minimization of environmental damage, have become important current issues. This paper presents of numerical simulation for several the thermoelectric materials. Numerical simulation is carried out by using a finite element package ANSYS. Maneewan et al., [11] conducted an experimental investigation on TEC1-12708 type of thermal comfort study of compact thermoelectric air conditioner. In this paper the cooling performance of compact thermoelectric air-conditioner was analysed. The compact TE air conditioners COP was calculated to its optimum parameters. Then analyse the COP with respect to time at various considerations. Manoj and Walke [12] conducted an experimental study of thermoelectric air cooling on cars by replacing the existing HVAC system with newly emerging thermoelectric couple or cooler which works on Peltier and Seebeck effect. Yadav and Mehta et al., [13] presented combined experimental and theoretical study of thermoelectric materials and its applications. The present study develops an optimization design method for thermoelectric refrigerator. This device is fabricated by combining the standard n- and p-channel solid-state thermoelectric cooler with a two-element device inserted into each of the two channels to eliminate the solid-state thermal conductivity. Manoj Kumar et al., [14] presented an

experimental study of novel potential green refrigeration and air-conditioning technology to analyse the cause and effect of an existing air-condition system. Thermoelectric cooling provides a promising alternative R&AC technology due to their distinct advantages. The available literature shows that thermoelectric cooling systems are generally only around 5–15% as efficient compared to 40–60% achieved by the conventional compression cooling system. Huang. B et al., [15] fabricated an experimental set up of thermoelectric cooler to analyse it at various operating considerations. The system simulation shows that there exists a cheapest heat sink for the design of a thermoelectric cooler. It is also shown that the system simulation coincides with experimental data of a thermoelectric cooler.

After studying the literatures on thermoelectric cooler modules from various publications, it was concluded that most of the researchers have focused directly on numerical studies, fabrication, experimentation and improvement of TEC module details to find out the COP of the Thermoelectric Cooler Module under varied operating conditions. Hence authors found a little bit gaps on modeling and analysis of thermoelectric cooler modules of various materials like Copper and Aluminium fins. It was tested with temperature and heat flux distributions under varied operating conditions.

MODELING ANALYSIS

The thermoelectric cooler (TEC) modules are modeled in CATIA and analyzed in ANSYS. The pictorial representations of TECs are shown in figures 1, 2 and 3 with the selection of Aluminium and Copper fin type materials.

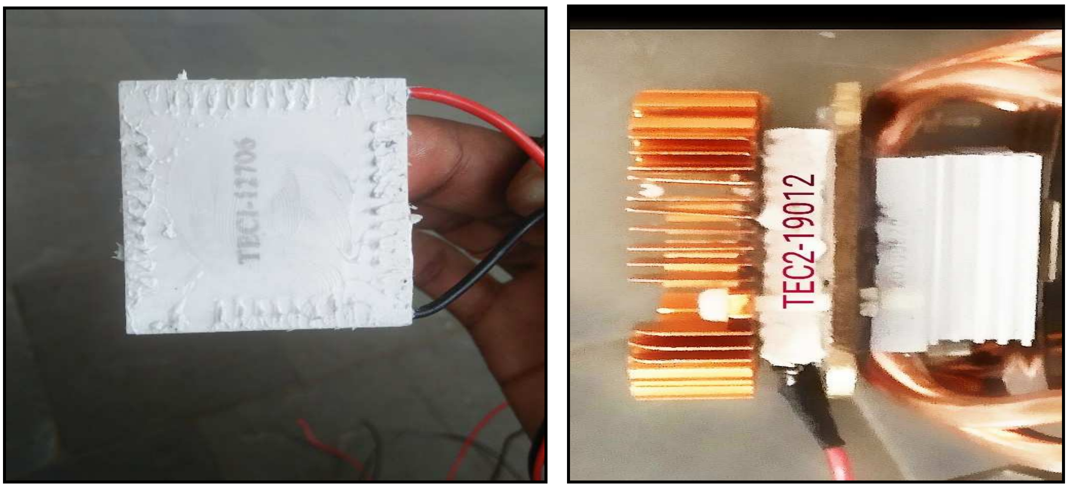

Figure 1: Pictorial Representations of Thermoelectric Cooler Modules

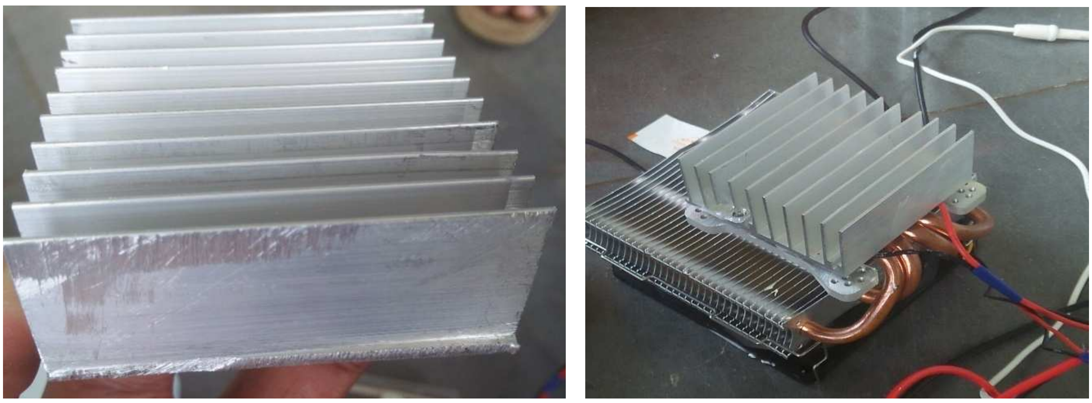

Figure 2: Pictorial Representations of Aluminium Fins on Thermoelectric Cooler Modules

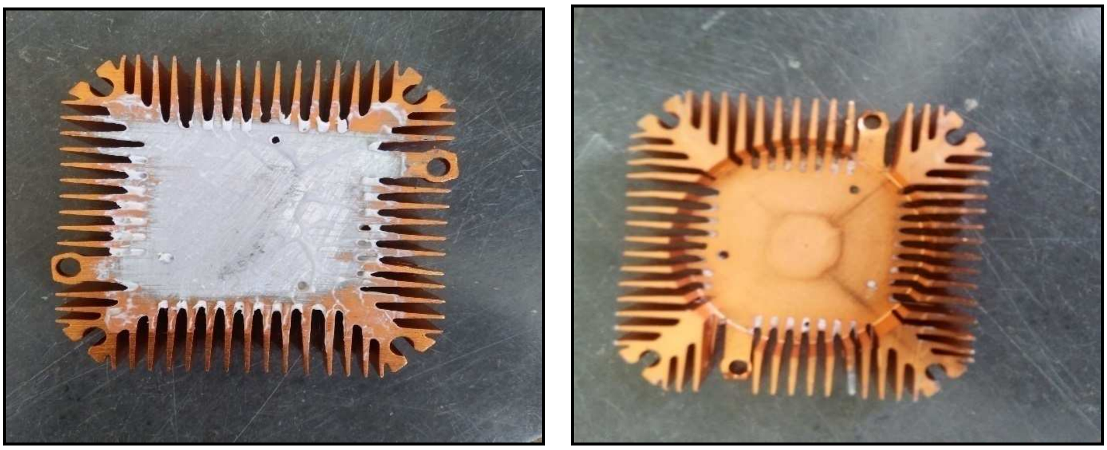

Figure 3: Pictorial Representations of Copper Fins on Thermoelectric Cooler Modules

Table 1: Model Specification and Parameter Estimation in Fixed Effect Model

S. No	Name	Specifications
1	Material	Chip model: TEC2-19012, Silicon –Bismuth
2	Area dimensions (mm)	40*40*7.3
3	Maximum operating température (^{0}C)	80
4	Q max (W)	33.3 W
5	Vmax (DC)	12V
6	Imax (A)	12
7	Work environment temperature (^{0}C)	- 55 ^{0}C to 83 ^{0}C
8	Storage condition	- 40 ^{0}C to 60 ^{0}C

Table 2: Specifications of Copper and Aluminium Fins on Thermoelectric Cooler Module

S.No	Name	Copper Fin Specifications	Aluminium Fin Specifications	Units
1	Isotropic Thermal Conductivity	386.7	237.5	$\frac{w}{m-^{o}C}$
2	Density	8940	2689	$\frac{K}{m^3}$
3	Specific Heat Constant Pressure	385	951	$\frac{J}{Kg-^{o}C}$

STEADY STATE THERMAL ANALYSIS OF COPPER AND ALUMINIUM FINS ON THERMOELECTRIC COOLER (TEC) MODULE

Fins are used to enhance the convective heat transfer in a wide range of engineering applications, and offer a practical means for achieving a large total heat transfer surface area. Fins are commonly applied for heat management in electrical appliances such as computer power supplies or substation transformers. Other applications include IC engine cooling; such as fins in a car radiator. It is important to predict the temperature and heat flux distribution within the fin in order to choose the best configuration that offers maximum effectiveness. This exercise serves as a visualization tool for evaluating the effect of shape on fin effectiveness, efficiency and temperature and heat flux distribution. Hence the ANSYS/Thermal products support steady-state thermal analysis. A steady-state thermal analysis calculates the effects of steady state thermal loads on a system or component. Engineer/analysts often perform a steady-state analysis before doing a transient thermal analysis, to help to establish initial conditions. A steady-state analysis can also be the last step of a

transient thermal analysis. Steady-state thermal analysis can be performed to determine temperatures, thermal gradients, heat flow rates and heat fluxes in an object are caused by thermal loads. A steady-state thermal analysis may be either linear with constant material properties; or nonlinear with material properties that depend on temperature. The thermal properties of most material do vary with temperature. So the analysis usually is nonlinear. Steady state analysis of the copper and aluminium fins on Thermoelectric Cooler (TEC) Module performance were carried and compared under the electric input current supply of 6 and 3 amperes.

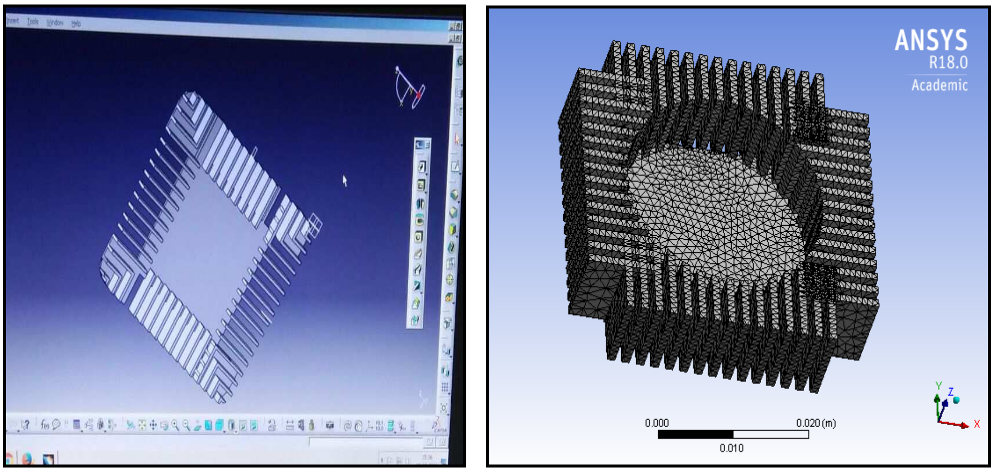

Figure 4: Modelling and Analysis of Copper Fin in Catia V5 and ANSYS

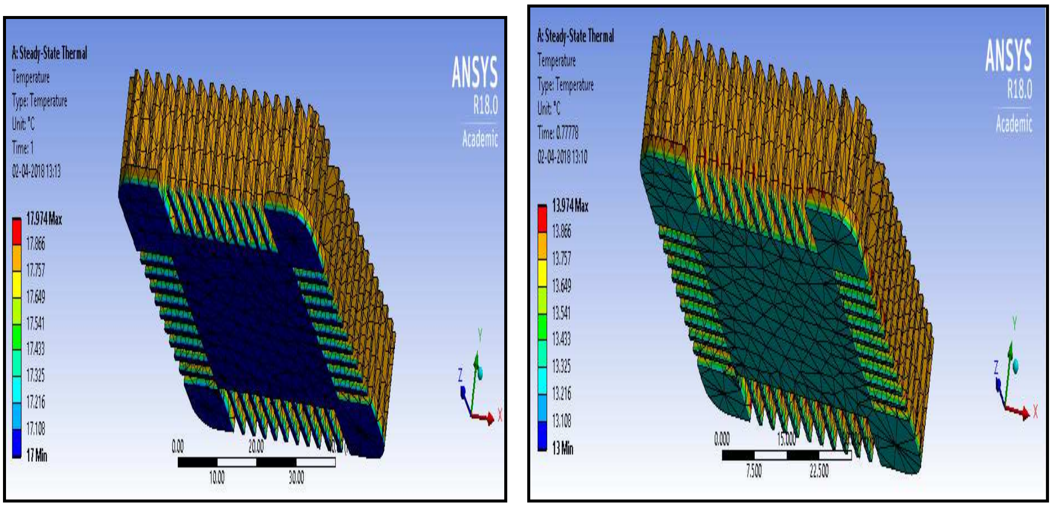

Figure 5: Comparison of Temperature Distributions in Copper Fin at 3 and 6 amps Current

Figure 5 shows that comparison has been made on Copper fin thermoelectric cooler module by applying 3 and 6 amps input power supply has given a cooling effect temperature of 17.97 ^{0}C and 13.97 ^{0}C. It shows that higher cooling effect is observed when high input power supply is given and the reason is that large amount of heat rejection is taking place from cooler module.

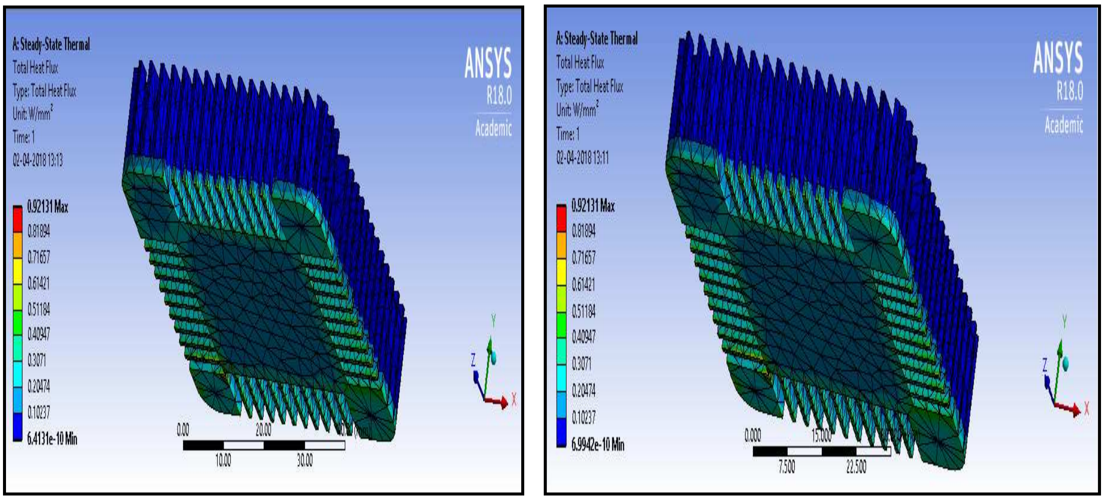

Figure 6: Heat Flux Distribution of Copper Fin at 3 and 6 amps Input Current

Heat flux distribution in Copper fins of thermoelectric cooler module is shown in figure 6 indicates that from TEC module to upper surface of the fin, the contour colours changes from blue to red based on temperature value. Heat flux means amount heat released for unit area of the copper fin from 6.4131e^{-10} to 6.92131e^{-10} W/mm^2 for a solar electric input power supply of 3 amps. Heat flux distribution is from 6.992e^{-10} to 6.92131e^{-10} W/mm^2 for an electric input power supply of 6 amps

STEADY STATE THERMAL ANALYSIS OF LONG AND SHORT ALUMINIUM FIN

Modeling and meshing of long Aluminium fin for thermoelectric cooler module is designed using CATIA Version 5 and in ANSYS is shown in figure 7. Temperature distribution takes place from TE module to the upper surface of the fin shown in figure 8 and the colour contours changes from blue to red based on temperature value. So 18.268 ^{0}C is attained at entrance of the cooling chamber for a copper fin with a temperature loss of 1.268 ^{0}C for the case of 6 amps input power supply and 14.55 ^{0}C at entrance of the cooling chamber in case of Aluminium fin. The surroundings temperature is maintained at 33 ^{0}C. Heat flux distribution in Aluminium fins of thermoelectric cooler module is shown in figure 9 indicates that from TEC module to upper surface of the fin, the contour colours changes from blue to red based on temperature value. Heat flux means amount heat released for unit area of the Aluminium fin from 137.02 to 21328 W/mm^2 for an electric input power supply of 3 amps.

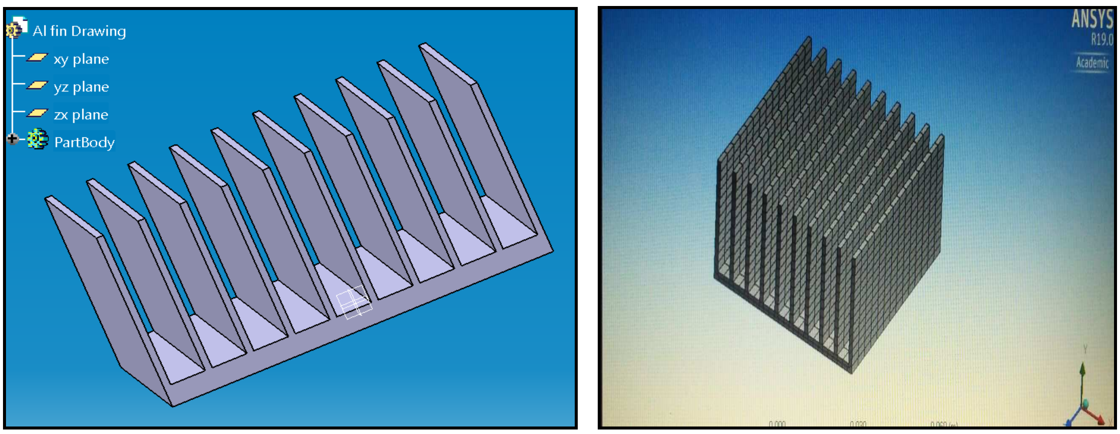

Figure 7: Modelling and Analysis of Long Aluminium Fin in CATIA and ANSYS

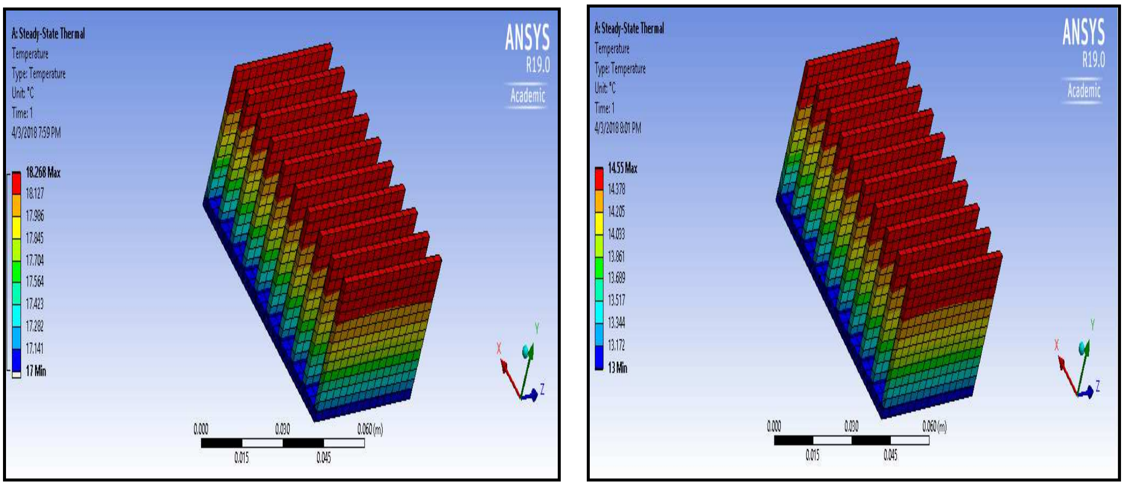

Figure 8: Temperature Distribution of Long Aluminium Fin at 3 and 6 amps Input Current

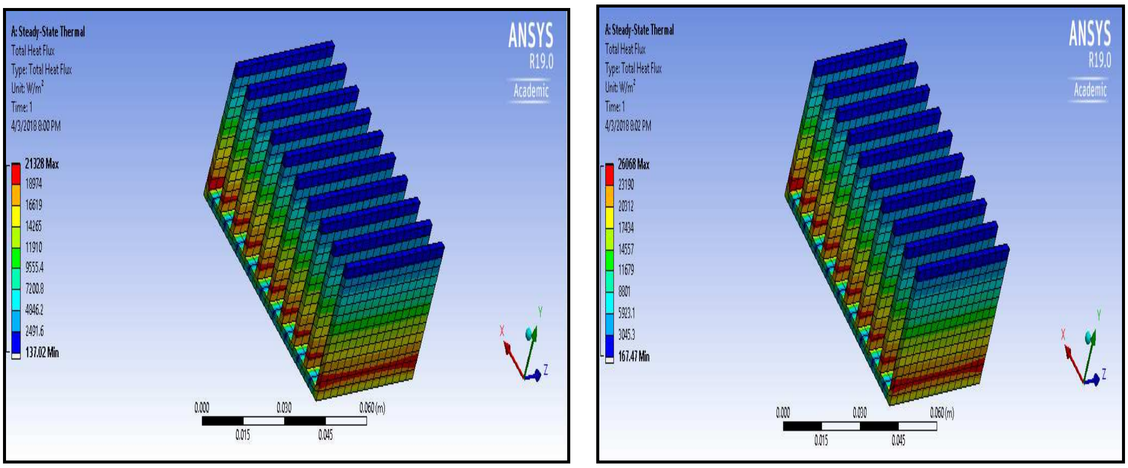

Figure 9: Heat Flux Distribution of Aluminium Fin at 3 and 6 amps Input Current

Heat flux distribution is from 167.48 to 26068 W/mm^2 for an electric input power supply of 6 amps. Hence it shows that more amount of heat flux distribution is taking place when high input electric power is supplied.

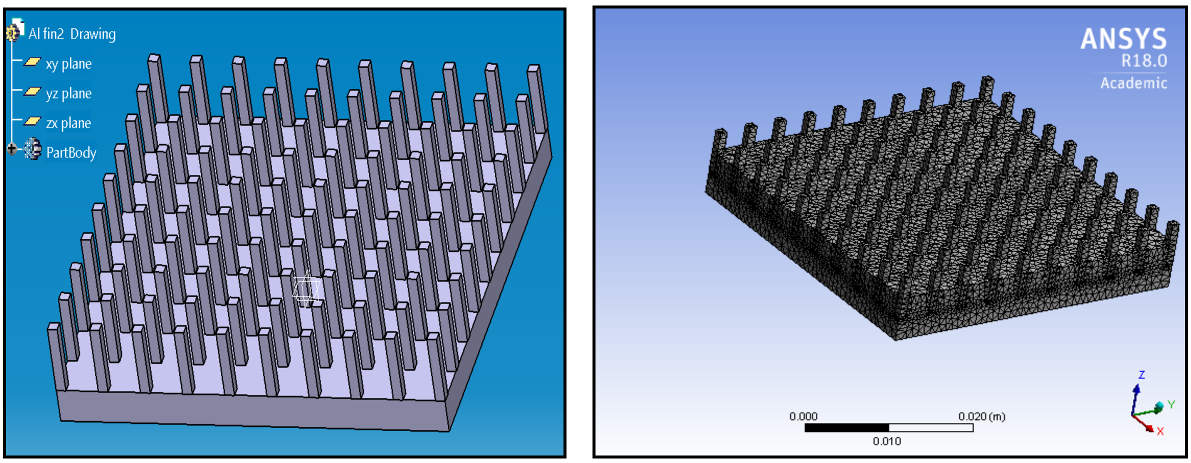

Figure 10: Modelling and Analysis of Short Aluminium Fin in CATIA and ANSYS

Modelling and meshing of short Aluminium fin for thermoelectric cooler module is designed using CATIA Version 5 and in ANSYS is shown in figure 10.

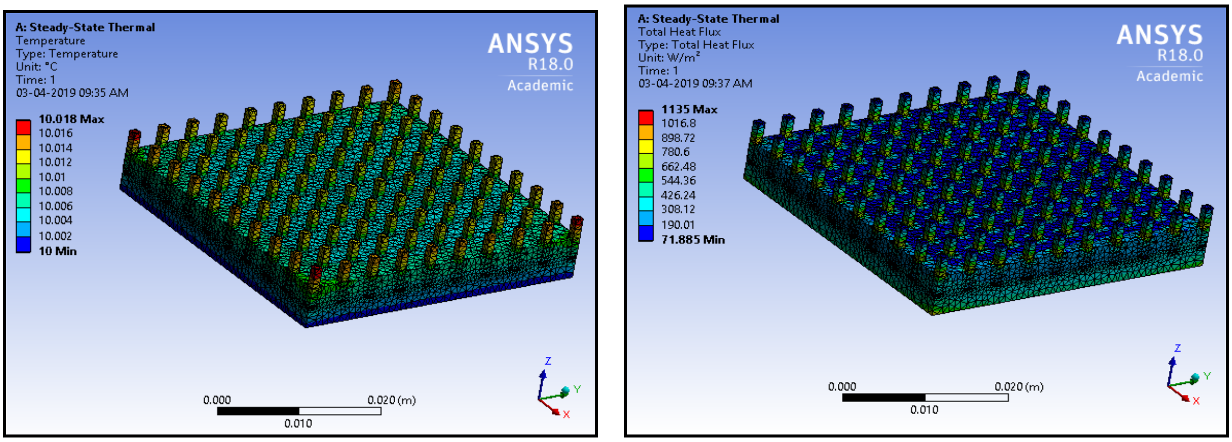

Figure 11: Temperature and Heat Flux Distribution in Short Aluminium Fin Using ANSYS

Temperature distribution takes place from TE module to upper surface of the fin is shown in figure 11. The color contours changes from blue to red based on temperature value. So in this case the temperatures attained are 10 ^{0}C at entrance of the cooling chamber and after reaching the temperature from bottom to top, the heat loss takes place around 0.018 at an ambient temperature 33 ^{0}C. The solar electric power input supply is 6 amps.

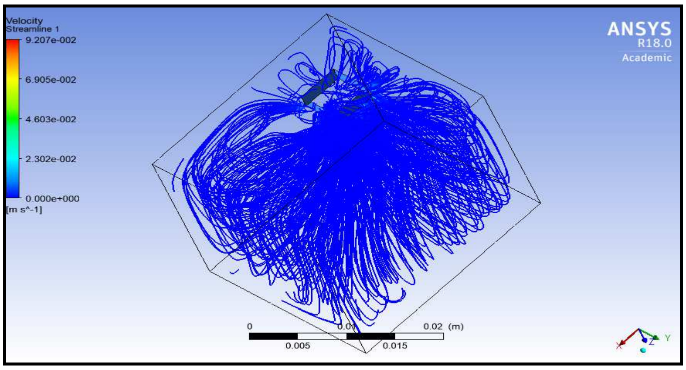

Figure 12: Cooling air Distribution in Cooling Chamber

Heat transfer takes place from module to cooling chamber is shown in figure 12 with some temperature distribution in the absence of fan at cold reservoir of TEC module. If the fan is placed on the cold reservoir, flow distribution will be different and will get more cooling in the cooling chamber.

CONCLUSIONS

This modelling and simulation of thermoelectric cooler module indicates with air-cooling with different sinks on cold reservoir like copper and aluminium fin materials. It is quite easy to achieve the significant temperature difference in the single stage TE module, but, the COP of the single stage module is very less for the domestic use. Cooling effect in cooling chamber is increased with increased electric current input to the TE module. Cooling effect is more in case of 6 amps solar energy input compared to 3 amps input.

- The TE devices can act as coolers, heat pumps, power generators, or thermal energy sensors and are used in almost all the fields such as military, aerospace, instrument, biology, medicine, industrial or commercial products. The major challenge faced in TE cooling is lower COP especially in large capacity systems.
- It can be concluded that by selecting good materials for thermoelectric module and heat sinks, efficiency is still further improved and by providing the thermoelectric modules in series the efficiency can also rise further.
- With the increase of temperature differences between the junctions, so that the efficiency of thermoelectric module is increased.

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